Since January 2020 Elsevier has created a COVID-19 resource centre with free information in English and Mandarin on the novel coronavirus COVID-19. The COVID-19 resource centre is hosted on Elsevier Connect, the company's public news and information website.

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Drop in urban air pollution from COVID-19 pandemic: Policy implications for the megacity of São Paulo☆

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Letter to the editor

According to the World Health Organization, there are 4.0 million confirmed cases of Coronavirus disease (COVID-19) spread over 215 countries and 278,892 confirmed deaths, as of May 10, 2020 (WHO, 2020). The first confirmed case in South America was recorded in Brazil on February 25, 2020; a passenger arriving at Guarulhos International Airport from Northern Italy (Rodriguez-Morales et al., 2020). This airport is located in the Metropolitan Area of São Paulo (MASP), which is the largest urban agglomeration in the Southern Hemisphere with 21.7 million inhabitants (10.3% of Brazil's population). MASP is a leading center for services, finances, shopping and industries, and has the country's largest vehicular fleet, with 13.9 million units. On-road vehicles emitted 115, 43, and 1.1 Gg of carbon monoxide, nitrogen oxides (NOx), and particulate matter, respectively, in 2018 (CETESB, 2019).

Nitrogen oxides are mainly emitted by human activities (e.g., road transportation, industrial manufacturing, biomass burning) (Peel et al., 2013), contribute to ozone production (Monks et al., 2015) and secondary aerosol formation (Fuzzi et al., 2015), and to acid deposition and eutrophication (Peel et al., 2013). In urban areas, NOx consists of NO and NO_2, with the latter associated with negative health effects (Mills et al., 2015). Curbing NOx emissions may also reduce global warming, since NOx is co-emitted with climate forcers, such as carbon dioxide and black carbon (BC) particles.

On March 24, 2020 the State of São Paulo (estimated population of 45.9 million in 2019) was put on lockdown due to the increasing number of cases of COVID-19. The quarantine was enforced in an attempt to stop the spread of the virus, closing non-essential shops, shutting schools and universities and banning gatherings. Since the onset of the lockdown, the number of vehicles circulating on the roads and flights has been severely reduced, with immediate improvements in the air quality across the MASP. Fig. 1a and b shows the daily mean NOx concentrations at 13 monitoring stations in the MASP on weekdays of business as usual (BAU) (March 2–20, 2020) and on the first day of the lockdown (the cleanest day of the period March 24-April 3, 2020). To reduce the influence of meteorology on ambient concentrations, we only selected BAU days with similar weather conditions to the cleanest day. On BAU days, the highest mean concentration (± standard deviation) was observed at Congonhas station (125.8 ± 27.4 μg m^{-3}, located 500 m from the busy Congonhas airport) and the lowest at Pico de Jaraguá (17.3 ± 5.2 μg m^{-3}, on the city's outskirts). Comparing both periods, the largest absolute decrease in NOx concentrations was found at Congonhas (−79.6 μg m^{-3}), followed by Marginal Tietê (−59.2 μg m^{-3}, at the curbside of a highly-trafficked avenue). A substantial drop was observed for all stations with reductions varying between 34% (at Osasco) and 68% (at Pinheiros).

Similar NOx pollution reductions (40–70%) were observed when comparing the BAU period prior to the national truck drivers' strike (May 1–20, 2018) and the cleanest day of this unprecedented event (May 28, 2018) (Fig. 1c and d). This strike stopped Brazil for 10 days starting on May 21, as a protest against the high price of diesel fuel (Leirião et al., 2020). Because truck freight accounts for 61% of Brazilian transport-related expenditure services (Barros et al., 2015), this event prompted the closing of most of the country's gas stations when they ran out of fuel, the halt of vehicular traffic, the closing of schools, universities, and 10 major airports.

Note that for the BAU periods, the concentrations in May 2018 were higher than in March 2020, in connection with typically more stable atmospheric conditions that prevents air pollution dispersion (Carvalho et al., 2015). We suggest that the drop in NOx concentrations observed during these two events were mostly linked to reductions in fossil fuel combustion, since biomass burning smoke —another source of air pollution in the region— occurs between August and October (Targino et al., 2019). More specifically, the improvement in air quality was due to the reduction in traffic emissions, since this sector contributes 67% to the NOx emissions in the MASP (CETESB, 2019). The intersite variability of NOx drop may be explained by the different distances between the monitoring sites and main roads as well as the different traffic rates.

Because NOx and BC concentrations are highly correlated in traffic-dominated areas (e.g., Krecl et al., 2019), we expect a similar reduction of these concentrations when traffic volume decreases. In fact, Targino et al. (2018) observed a 88% drop in ambient BC concentrations when comparing weekday and Sunday measurements (from 8.5 to 1.0 μg m^{-3}) on a busy avenue in São Paulo's city center, attributed to the closing of the avenue for motorized traffic on

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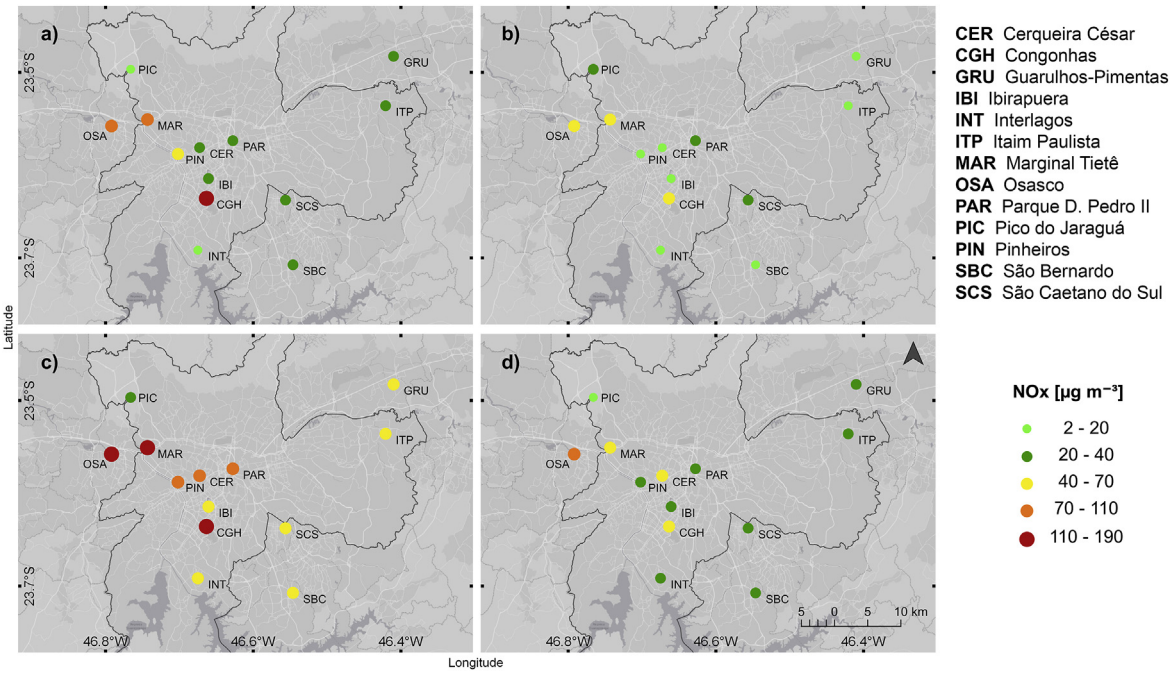

Fig. 1. Daily mean NOx concentrations in the MASP on weekdays: a) March 2–20, 2020, b) March 24, 2020 (cleanest day in the lockdown period), c) May 1–20, 2018, d) May 28, 2018 (cleanest day in the strike period). The black line delimits the boundaries of the city of São Paulo within the MASP.

Sundays.

The combined mean NOx reduction of 34.6 µg m^{-3} observed during the COVID-19 and truck drivers' strike largely surpassed the NOx decrease of 1.82 µg m^{-3} yr^{-1} reported for the MASP in the period 1996–2009 (Carvalho et al., 2015). This suggests that enforcing more stringent policies on vehicle emissions may lead to a quick improvement in the air quality in the MASP. Note that aircraft operating at Congonhas airport emitted very little NOx compared with the heavy-duty diesel vehicles (HDDV) circulating in the MASP in 2018 (1 vs. 30 Gg of NOx) (ANAC, 2019; CETESB, 2019). Even though the HDDV represent only 3.1% of the on-road fleet, they should be particularly targeted because of their large emissions and average age of 12.4 years (equivalent to Euro III technology) (CETESB, 2019). Thus, several actions should be undertaken in relation to the HDDV: i) application of more stringent emission limits (Euro VI-equivalent) before the target date in 2023 (Miller and Posada, 2019), ii) renewal of the public transport bus fleet and iii) implementation of regular vehicle inspection and maintenance (I/M) programs, not currently in place, especially for small and medium urban trucks (average age of 16 years, equivalent to Euro II technology).

In concluding, curbing vehicular emissions has been widely advocated as an essential measure to decrease air pollutant concentrations in cities. Despite being totally unrelated events, the lockdown and the truck drivers' strike created a large-scale experiment in which traffic emission contributions at various spatial scales could be estimated without using complex dispersion models. Moreover, ground-based data as reported here not only captured the NOx gradients at local level, but it also highlighted the importance of having a permanent air quality monitoring network across the country as a tool for policy makers.

The results shown here anticipated what the air quality in cities would look like if the world switched to a low-carbon economy, leading also to climate co-benefits. They can be used as a foundation to develop more stringent regulations to decrease the exposure of urban population to air pollutants.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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